A 3D SCANNING SYSTEM BASED ON LASER TRIANGULATION AND VARIABLE FIELD OF VIEW

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ABSTRACT

The most efficient 3D scanning systems use either the principle of laser triangulation or the principle of Time of Flight – TOF. In triangulation based systems, the range and depth variation are limited, but they have a great precision. On the other hand the opposite occurs to TOF systems have low precision, great range and depth variation. This work describes a development of a 3D scanning system, with precision and range better than traditional laser triangulation 3D scanners, and also, it is as versatile as TOF systems. A prototype of the proposed system had been implemented and the results are shown.

1. INTRODUCTION

Computer graphics allow us to render realistic digital images but, before these images can be rendered, 3D digital models must be available. Generally, these models are obtained by 3D modeling, a very slow process and limited in realistic details. This work describes the project and implementation of an automatic 3D data acquisition system of real objects using range sensors. This is a high definition acquisition system and it fits to applications in the most various civil and governmental segments. The benefits of this project can be defined by a set of possible applications and services: cave mapping; inspection of structural failures on dams, bridges, towers and buildings; rapid prototyping; topologic mapping [1]; virtual museum; studies on how statues were sculpted [2]; volumetric calculation; mass estimation; imaging of the International Space Station [3]; 3D animation and movies; determination of the body mass rate.

2. PROJECT DESCRIPTION AND IMPLEMENTATION

The system is composed by 6 modules: (*a*) image acquisition module; (*b*) scanning module: (*c*) control software: (*d*) distance estimation module; (*e*) 3D image reconstruction; and (*f*) output graphic interface (See Figure 1).

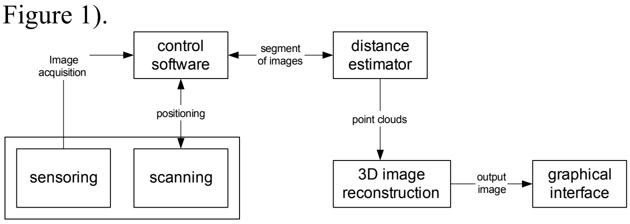

Figure 1- 3D scanning system: sensoring and scanning modules are implemented in hardware (image acquisition system) and the other modules in software.

2.1. BRIEF DESCRIPTION OF THE MODULES

Image Acquisition Module
This module is responsible by the input image acquisition. It is composed by (*i*) a video camera (NTCS 4.2~50.4 mm, CCD 1/3"); and (*ii*) a video acquisition board (640x480 resolution pixels).

Scanning Module
This module is composed by (*i*) a laser with line generator and three motion controllers; and (*ii*) engines with gear heads and encoders, responsible for the system scanning. The motion controllers command the engines and one of them also activate the laser. All these devices are controlled by a host computer, connected through a serial port interface (RS232-C).

3D Control Software
The 3D control software is a routine that has as its input a sequence of video frames, which passes by a distortion correction process caused by intrinsic camera parameters. This correction is performed by a camera calibration using a four-step procedure with implicit image correction, described by Heikkilä and Silven [4]. This procedure can be used in many computer vision applications, but its biggest benefit is to do measurements based on not only

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cameras but also in robotic vision, where there is the need of high precision geometry.

Distance Estimator Module

This procedure uses explicit camera calibration methods for 3D coordinate mapping on the image and implicit approach to distortion correction [5]. Next step is focused on image segmentation, applying a median filter for noise elimination, edge detection using Prewitt filter [6] or Canny [7] and threshold for image digitization. Segmented images are used to determine its depth, based on active triangulation technique. The output of this module is a cloud point image.

3D Image Reconstruction Module

This module uses the cloud point image as its input; makes use of image processing techniques such as: image alignment and image fusion; and perfectly reconstructs the main object.

Output Graphic Interface

It is a friendly user interface that allows setting and modifying some parameters like: scanning ranges, image acquisition resolution, segmentation, depth threshold, save image, image preview, laser and camera calibration.

2.2. THE PRINCIPLE OF TRIANGULATION

The principle of triangulation cares on the projection of a light pattern, i.e., a line is projected by the laser over an object and captured by the digital camera. The distance from object to system can be calculated by trigonometry, as long as you know a priori distance between the scanning system and the camera [8]. An example of the triangulation system configuration is showed in Figure 2.

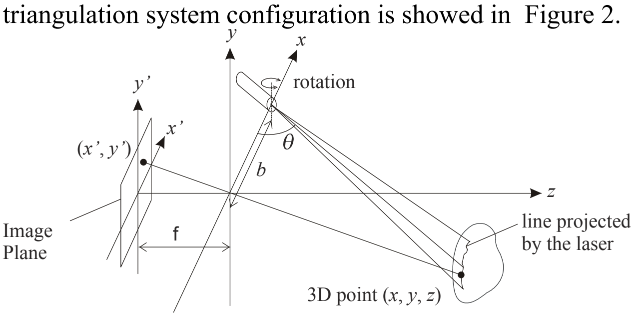


Figure 2. Geometry of triangulation technique: the lens are located at the origin, with focal length *f* to the image plane, and baseline *b* between the projector and the camera.

The laser projection forms θ angle with the baseline [9], and 3D point (x,y,z) in the real space is projected to the image pixel (x', y'), following equations (1) and (2):

$$x' = \frac{xf}{z} \quad (1) \qquad y' = \frac{yf}{z} \quad (2)$$

The real coordinates of a point follow equations (3), (4) and (5):

$$x = \frac{bx'}{f\cot\theta - x'} \quad (3) \qquad y = \frac{by'}{f\cot\theta - x'} \quad (4) \qquad z = \frac{bf}{f\cot\theta - x'} \quad (5)$$

The value θ is given by the motor encoder; the focal length f is calculated by camera calibration; and the baseline *b,* equation (6), is calculated by positioning the laser source in the point where its projection coincides to the *center* of the image (pointing to an object at a known distance *z*.)

$$b = \frac{z}{\tan\theta} \quad (6)$$

First an horizontal scanning of the object is performed with the laser projecting a vertical line. Then, images are captured and the respective values of θ, obtained by the encoder to each image, are registered. To each captured image, the values of x' and y' are determined. The laser is reflected and the real coordinates are calculated by equations (3), (4) and (5). Figure 3 illustrates the procedure, showing at the center the laser line during the horizontal scanning. A point of the laser line projection tends to left or right depending on the distance z.

Figure 3. Video acquisition frame

The 3D scanning system proposed in this work differs from conventional triangulation systems in the scanning procedure and variable field of view (FOV). In conventional systems data acquisition is obtained only by moving the laser, while in this project both the camera and the laser are moved. The original equations of triangulation (3), (4), and (5), were modified to get the camera rotation. In this way we have equations (7), (8), and (9), as follows:

$$x = \frac{x'\left(\dfrac{b\cdot\tan\theta\cdot\tan(90-\alpha)}{\tan(90-\alpha)+\tan\theta}\right)\Big/ sen(90-\alpha)}{f\cot(\theta+90-\alpha)-x'} \quad (7)$$

$$y = \frac{y'\left(\dfrac{b\cdot\tan\theta\cdot\tan(90-\alpha)}{\tan(90-\alpha)+\tan\theta}\right)\Big/ sen(90-\alpha)}{f\cot(\theta+90-\alpha)-x'} \quad (8)$$

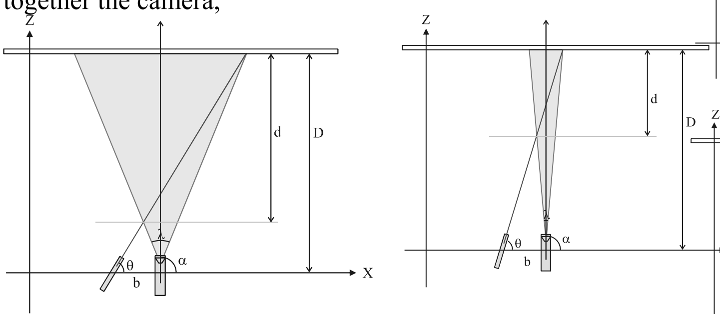
$$z = \frac{f\left(\dfrac{b\cdot\tan\theta\cdot\tan(90-\alpha)}{\tan(90-\alpha)+\tan\theta}\right)\Big/ sen(90-\alpha)}{f\cot(\theta+90-\alpha)-x'} \tag{9}$$

considering that the focal line, related to f of the camera, is located at an angle α in relation to baseline b.

2.3. THE SCANNING PROCEDURE

The scanning procedure must cover the entire desired scene surface, so that there is a motion controller and a motor with encoder, to each one of the three scanning axes, as follows. Both camera and laser have independent rotation control at *Y-axis* (vertical), and rotate together at *X-axis* (horizontal). The motion controller controls the motor positioning, the speedy and the acceleration, by a serial interface (RS232-C). The scanning system also controls the FOV of the camera.

First, a previous acquisition with low resolution and maximum FOV is performed. The camera is pointed to the center of the scene in order to determine the maximum distance *D* (between the camera and the target object). To determine this maximum distance, the scanning is made only by laser. Then, FOV is adjusted according to the desired resolution (the smaller is FOV, the better is resolution, and the smaller is depth variation) (Figure 4), and it is made the vertical scanning at *Y-axis,* rotating together the camera,



(a) (b)

Figure 4. In (a) the FOV λ and the depth variation *d* are bigger than (b).

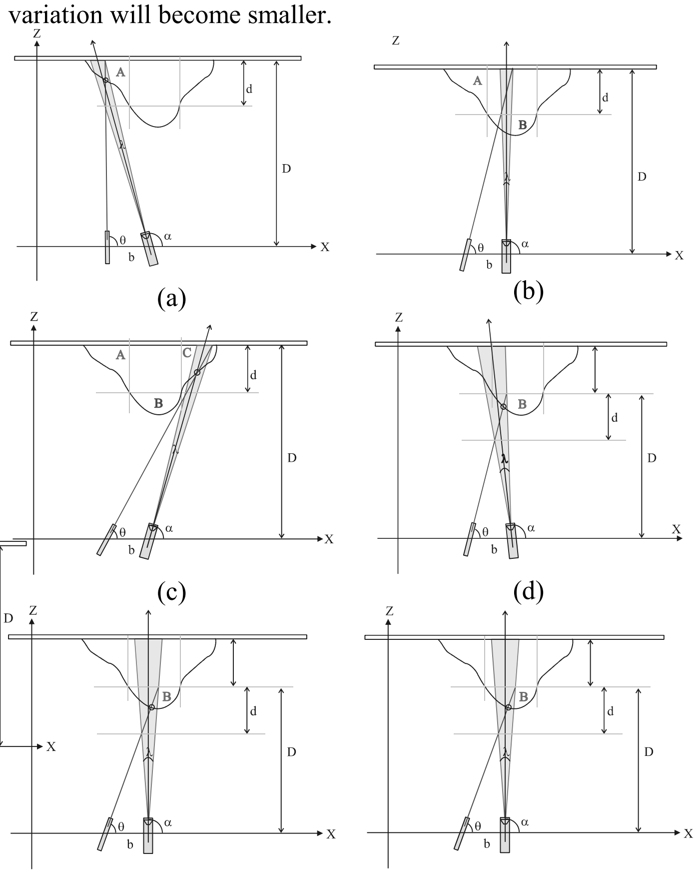
and the laser (Figure 5), and the laser angle is related to the camera angle as shown by equation (10):

$$\theta = \tan^{-1}\left(\frac{D}{D/\left(\tan(\alpha-(\lambda/2))+b\right)}\right) \quad \text{for} \quad \frac{D}{D/\tan(\alpha-(\lambda/2))+b} \geq 0$$

$$\theta = \tan^{-1}\left(\frac{D}{D/\left(\tan(\alpha-(\lambda/2))+b\right)}\right)+180 \quad \text{for} \quad \frac{D}{D/\tan(\alpha-(\lambda/2))+b} < 0 \tag{10}$$

where b is the baseline, and λ is FOV. The scanning is so that the laser corresponds to the right side pixels of the image (in a system with the laser at the left side of the camera). If the maximum distance D is known, the system will never make data acquisition in a longer distance.

After ending the scanning of a line, the system rotate the laser-camera set at *X-axis*, and continue making vertical scanning at *Y-axis*, until covering of the entire surface. After that, the system determines the regions which *d* exceeds the maximum depth variation *D* (region B of Figure 4a-c), and update its maximum distance, making *D* equal to *d*, adjusting FOV, and the laser angle θ, so that it continues at the right side of the image (Figure 4d). If this adjust does not occur, the depth variation will become smaller.



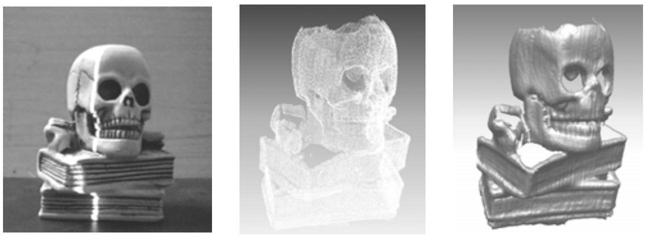
(a) (b) (c) (d) (e) (f)

Figure 5. Initial acquisition sequence (a) (b) (c). Adjusting the FOV and the angle of the laser (d). Second acquisition (d) (e) (f).

The system repeats the scanning in the *Y-axis* at regions close to *D* (region B of Figure 5d-f). This procedure repeats until all the regions are inside the depth variation field. The data acquisition is made by layers, making best use of the camera, obtaining best resolution at more distance, more range, and more depth, with smaller number of scanning, than conventional triangulation systems.

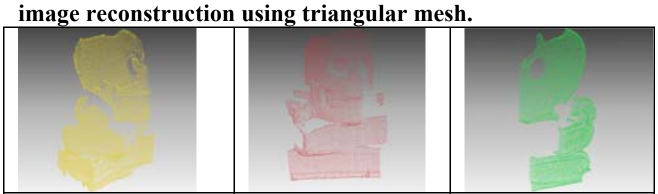
3. RESULTS

A prototype of the system was developed and results are presented in this section. Figure 6 shows a reduced view of the image scanning using a mechanical reducing factor of 879:1. As described in the previous sections images are captured by the image acquisition system, Figure6a; Figure 6(b) shows intermediate 3D information plotted as a point cloud; and Figure 6(c) shows a 3D reconstruction of the scene using the triangular mesh technique. For this scene we used images captured by different angles and resolutions, Figure 7a-c. Figure 8 shows the image reconstructed by the alignment of images in Figure7a-c; Figure 8b shows the triangular surface creation; and finally, Figure 8c shows the output image after the effects of the fusion techniques.



(a) (b) (c)

Figure 6. (a) Data acquisition scene (source image). (b) 3D image reconstruction represented by point clouds. (c) 3D image reconstruction using triangular mesh.



(d) (e) (f)

Figure 7. (a) Point clouds obtained by different angles and resolution. (a) 80522 points; (b) 87093 points; (c) 69320 points.

(a) (b) (c)

Figure 8. (a) Image reconstructed by alignment technique; (b) triangular surface creation; (c) image reconstructed by fusion technique

5. CONCLUSIONS AND FUTURE WORKS

The present paper has described the project and implementation of a low cost system for 3D image scanning, based on laser triangulation and FOV techniques. It enables a perfect 3D image reconstruction with high resolution from different angles, colors and depth variation. Future works are concerned on the improvement of the sensoring module, motion controller module and control software. For the sensory module, the use of more robust digital filters and high-speed/resolution cameras, for image acquisition, are proposed. Moreover, for both motion controllers and control software its implementation on high-density field programmable gate arrays (FPGAs) is proposed. This improvement will enable system reconfiguration, low-power, low-area and embedded processing.

6. REFERENCES

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